

Unit 10: General Wave Properties

In-depth theoretical concepts, mathematical derivations, wave characteristics, wave behaviors, Simple Harmonic Motion (SHM), and damped oscillations.

INSTITUTE

KARACHI EDU COACHING CENTER

SUBJECT

Physics (Sindh Board / FBISE)

TARGET

Secondary School Examination

Wave Motion & Energy Transfer Mechanism

Definition of Wave Motion

A wave is a disturbance in a medium that carries energy from one point to another without transferring the matter of the medium itself.

Non-Matter Transfer Principle

Particles of the medium undergo periodic oscillation around their mean equilibrium position, passing kinetic and potential energy to adjacent particles while remaining in place.

Key Experimental Proofs



Water Ripple Demonstration

Dropping a stone creates circular ripples. A floating cork moves strictly up and down, proving water particles do not travel outwards.



Rope Vibration Experiment

Flicking one end of a tied rope sends a crest down its length. Red ribbon tied to the rope moves purely vertically.

Mechanical vs. Electromagnetic Waves

Mechanical Waves

Medium Requirement

Requires physical medium (solid, liquid, or gas). Cannot pass through vacuum.

Origin

Produced by physical mechanical vibrations of particles.

Key Examples

Sound waves, water ripples, seismic waves, spring oscillations.

Electromagnetic Waves

Medium Requirement

Does NOT require material medium. Propagates freely through vacuum.

Origin & Speed

Oscillating electric & magnetic fields. Speed = 3×10^8 m/s in vacuum.

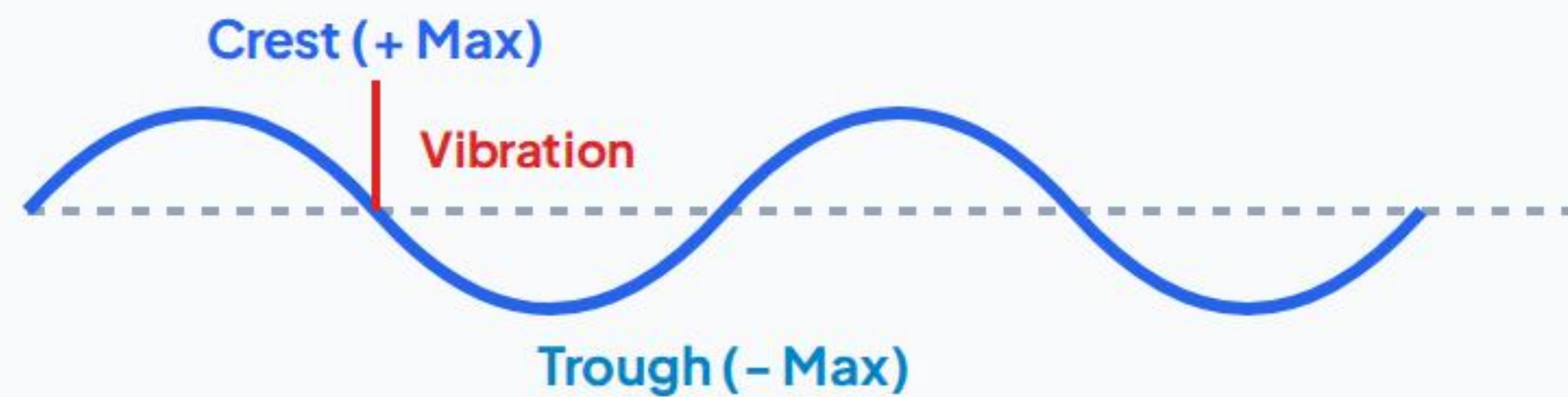
Key Examples

Visible light, radio waves, X-rays, microwaves, infrared, UV rays.

Transverse and Longitudinal Wave Mechanics

1. Transverse Waves

Particles vibrate **perpendicular** (90°) to the direction of wave propagation.



- **Crest:** Highest point above mean rest position.
- **Trough:** Lowest point below mean rest position.

2. Longitudinal Waves

Particles vibrate **parallel** to the direction of wave motion.



- **Compression:** High-density region where turns/particles crowd together.
- **Rarefaction:** Low-density region where turns/particles spread apart.

Wave Characteristics & Definitions

A

Amplitude (A)

Maximum displacement of a vibrating particle from its mean rest position. Measured in meters (m).

λ

Wavelength (λ)

Linear distance between two consecutive crests, troughs, compressions, or rarefactions. Unit: meters (m).

f

Frequency (f)

Number of complete wave cycles produced per unit time. Measured in Hertz (Hz) or s^{-1} .

T

Time Period (T)

Time required by any point on the wave to complete one full cycle of oscillation. Measured in seconds (s).

Derivation of Wave Equation ($v = f \lambda$)

Derivation Steps

By standard kinematic definition, wave speed v is distance traveled per unit time:

$$v = \text{Distance} / \text{Time} = S / t$$

If the distance traveled equals one wavelength ($S = \lambda$), the time taken is one period ($t = T$):

$$v = \lambda / T$$

Since frequency is reciprocal of time period ($f = 1 / T$), substituting gives:

$$v = f \times \lambda$$

Board Numerical Practice

TEXTBOOK EX. 1

Problem: A wave moves with speed 4.0 m/s. Its period T is 8.0 s and amplitude is 1.5 m. Find frequency and wavelength.

1. **Frequency:** $f = 1 / T = 1 / 8.0 = 0.125 \text{ Hz}$

2. **Wavelength:** $\lambda = v / f = 4.0 / 0.125 = 32 \text{ m}$

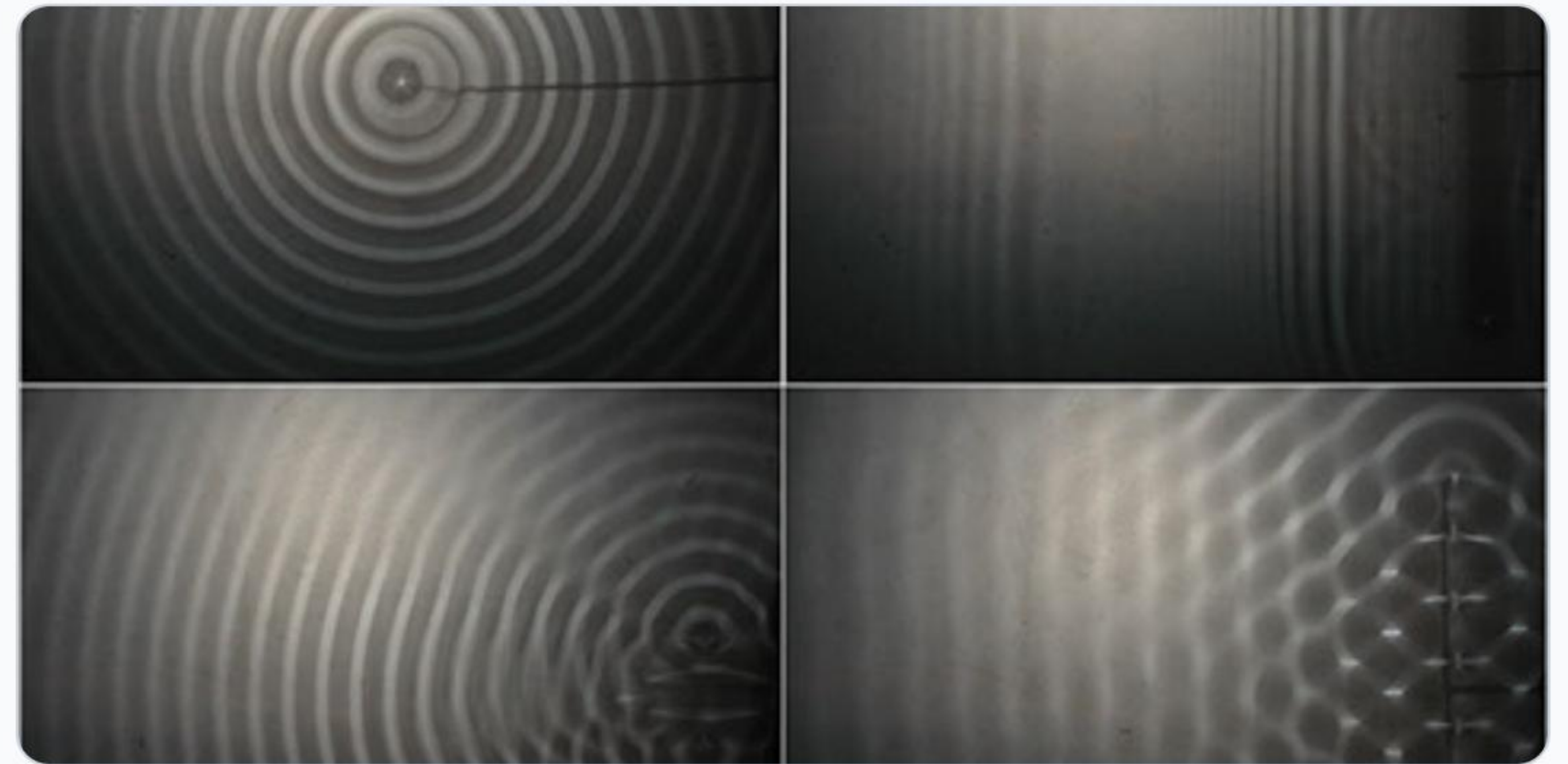
Ripple Tank Apparatus & Wavefronts

Ripple Tank Construction

A rectangular glass tray with water, illuminated from above by a lamp, projecting wave patterns on a screen below. Driven by an electric motor dipper.

Wavefront Types

- **Circular Wavefronts:** Produced by spherical point dippers.
- **Plane Wavefronts:** Produced by straight wooden bar dippers.



Wave Behaviors: Reflection, Refraction & Diffraction

1. Reflection

Bouncing Back

When waves striking a boundary between two media bounce back into the first medium.

Angle of Incidence (i) = Angle of Reflection (r)

2. Refraction

Bending Across Media

Change in direction and speed when entering from deep water to shallow water region.

Deep → Shallow: Speed & Wavelength Decrease

3. Diffraction

Spreading Around Gaps

Bending or spreading of waves around edges of obstacles or through narrow gaps.

Maximum spreading when Gap Size $\approx$ Wavelength

Simple Harmonic Motion (SHM) Conditions

Formal Definition of SHM

Simple Harmonic Motion is a special type of periodic oscillatory motion in which the acceleration '**a**' of the body is directly proportional to its displacement '**x**' from the mean position and is always directed towards the mean position.

$$F \propto -x \quad \text{OR} \quad a \propto -x$$

Necessary Conditions for SHM

- 1 Presence of a Restoring Force continuously pulling to mean.
- 2 Inertia in the system allowing overshooting past equilibrium.
- 3 Frictionless environment for constant amplitude SHM.

Simple Pendulum Mechanics & Formula

Force Component Resolution

When bob of mass m is displaced by angle θ , its weight mg resolves into two components:

1. $mg \cos\theta$: Perpendicular to arc, balanced by string tension T .

2. $mg \sin\theta$: Tangential component directing bob back to equilibrium position. Serves as **Restoring Force**.

Time Period Formula

$$T = 2\pi \sqrt{l / g}$$

- **Length (l):** Time period is directly proportional to $\sqrt{l}$.
- **Gravity (g):** Time period is inversely proportional to $\sqrt{g}$.
- **Mass & Amplitude:** T is completely independent of bob mass and angular displacement amplitude!

Ball and Bowl System Oscillations

Mean Position O

At bottom of bowl, net force on ball is zero. Weight mg acts downwards and normal reaction R acts upwards. Ball is at equilibrium.

Extreme Position A

When ball is placed at height A and released, component of weight acts as restoring force pulling ball toward bottom O.

Energy Interconversion

At Extremes (A & B):

Velocity = 0. Kinetic Energy = 0. Potential Energy is MAXIMUM.

At Mean (O):

Velocity is MAXIMUM. Potential Energy = 0. Kinetic Energy is MAXIMUM.

Damped Oscillations & Shock Absorbers

Damped Oscillation Definition

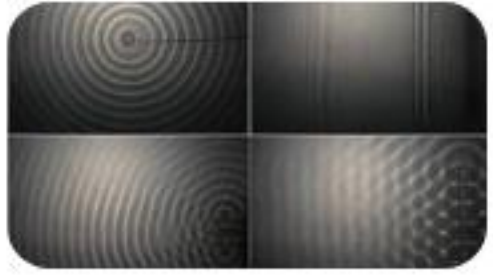
Oscillations in which amplitude progressively decreases over time due to resistive/frictional forces present in system.

Automobile Shock Absorbers

Piston moving inside viscous oil converts violent kinetic mechanical energy into thermal energy, providing smooth ride.



Image Sources



<https://serpmedia.org/scigen/images/e44-opener-ripple-tank08.jpg?crc=3793240015>

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<https://www.onallcylinders.com/wp-content/uploads/2018/08/07/Monroe-Shock-Absorber-Cutaway-Video.jpg>

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